

# PV FAQs

## Will we have enough materials for energy-significant PV production?

Reaching 20 gigawatts (GW) of annual PV sales in the United States by 2050 is a conservative goal. Twenty GW would equate to about 130 square kilometers, or 50 square miles, of PV modules. But will we have enough of the necessary feedstock materials to meet this desired production rate?

Producing PV modules and systems requires commodity materials such as glass, steel, concrete, copper, and plastic, as well as specialty materials such as purified silicon, indium, tellurium, or selenium. We will look at data on these materials and make certain assumptions to calculate the quantities that would be needed in the future.

In brief, our conclusion is this: Producing 20 GW/year of PV in the United States by 2050 would not create problems with materials availability. Issues surrounding the availability of PV materials at this level simply do not exist. Only indium and tellurium remotely approach becoming bottlenecks at this annual production rate, and simple strategies exist that would solve these problems, including extracting them from ores that are currently mined but unused, or that are used for other products. However, if production moved to 20 GW/year at a much faster pace—or if world PV production were to exceed 100 GW/year—either indium or tellurium could be serious bottlenecks (for  $\text{CuInSe}_2$  or  $\text{CdTe}$  cells) unless such cells were made much thinner or substitutes were found. However, as we discuss below, both of these research strategies seem to provide plausible solutions.

### Our Conservative Scenario

We consider only flat-plate PV systems and technologies already known and demonstrated. Present system efficiencies are about 10%; we assume a modest increase to 15% by 2050. We use an extremely conservative assumption that no technological advances will occur in the packaging or structural supports of PV systems (none of the necessary materials are sensitive to supplies).

Perhaps most importantly, our calculations are based on the rather unlikely scenario that only one type of PV technology will supply the entire 20 GW/yr of energy.

### Enough Commodity Materials?

Commodity materials are everyday products used in various parts of a PV system that do not relate to the actual generation of electricity from a PV module. Such materials include glass, steel, concrete, copper, and plastic. Most commodity materials would require little growth in production to offset growing demand for PV systems. As Table 1 shows, glass production would need to grow the most; however, a 0.13% annual growth rate is still a negligible amount.

### Enough Specialty Materials?

Specialty materials are used in varying degrees, depending on the PV technology. As shown in Table 2 (on reverse side), some materials would require a large percentage of current demand. However, consider: (1) the annual growth rate in supply over time; (2) whether the material is currently limited by supply or by demand; (3) whether it is a byproduct of a material that we already mine; and (4) how much of that byproduct currently goes unused. Thus, as Table 2 shows, the pace of materials needed in 2050 would pose no problems.

### What about Beyond 2050? Or at Higher Annual Production Volumes?

For silicon PV technologies, there are no availability limitations at any level of production. But for  $\text{Cu(In,Ga)Se}_2$  and  $\text{CdTe}$ , increasing production levels past 100 GW per year could be limited by indium and tellurium availability

Table 1. Commodity Materials: Projected Needs Versus Current Production

Material	Use in PV System	World Production	Materials Required <sup>b</sup>	% of Current Production	Annual Growth Needed <sup>b</sup>
Glass	Module	4,100 km <sup>2</sup> /yr	260 km <sup>2</sup> /yr	6.3%	0.13%
Plastic	Module	40 million MT/yr <sup>a</sup>	65,000 MT/yr	0.2%	Nil
Concrete	Support structure, roof mount	1.56 billion MT/yr	1.2 million MT/yr	0.1%	Nil
Steel	Support structure, roof mount	850 million MT/yr	1–2 million MT/yr	0.1–0.2%	Nil
Aluminum	Support structure, roof mount	24 million MT/yr	0.3–0.6 million MT/yr	1.3–2.5%	<0.1%
Copper	Wiring	14 million MT/yr	40,000 MT/yr	0.3%	Nil

<sup>a</sup>MT = metric tons  
<sup>b</sup>Necessary commodity production to reach annual PV system production of 20 GW/yr by 2050.



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**Table 2. Specialty Materials: Projected Needs Versus Current Production**

Technology	Material	World Production <sup>a</sup>	Materials Required <sup>a</sup>	% of Current Production	Annual Growth Needed (%)
Crystalline silicon	Purified silicon	25,000 MT/yr <sup>b</sup>	130,000 MT/yr <sup>b</sup>	520%	3.7% <sup>c</sup>
	Silver (grids/cell pads)	20,000 MT/yr	6,000 MT/yr	30%	0.53%
Thin-film Cu (In,Ga) Se <sub>2</sub> alloys	Indium	250 MT/yr (byproduct)	400 MT/yr	160%	2.0% <sup>d</sup>
	Selenium	2,200 MT/yr	800 MT/yr	36%	0.6% <sup>e</sup>
	Gallium	150 MT/yr	70 MT/yr	47%	0.9% <sup>f</sup>
Thin-film cadmium telluride	Tellurium	450 MT/yr (2,000 MT/yr unused, byproduct)	933 MT/yr	38% (of total, including unused)	2.2%
	Cadmium	26,000 MT/yr (byproduct)	800 MT/yr	3%	0.06%
Thin-film silicon	Germanium	270 MT/yr (3,200 MT/yr unused, byproduct)	40 MT/yr	1% (of total, including unused)	0.7%

<sup>a</sup>Necessary production for each type of PV technology to produce 20 GW/yr by 2050.  
<sup>b</sup>MT = metric tons  
<sup>c</sup>Elemental silicon is not constrained by supply; current production is low because of low demand.  
<sup>d</sup>Indium is a byproduct of zinc, which has been growing at 3%/yr for 50 years. Indium growth will probably exceed demand because of growth in zinc extraction. Zinc production would only have to increase 2%/yr to keep pace with demand.  
<sup>e</sup>Selenium is a byproduct of copper; an increase of only 0.16%/yr would keep pace with demand.  
<sup>f</sup>Gallium is not constrained by supply; current production is low because of low demand.

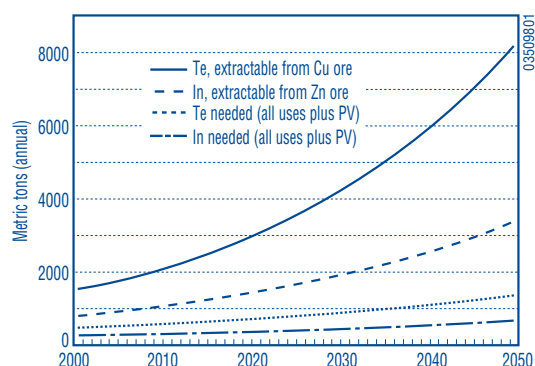
(see Figure 1). We would need to consider more aggressive extraction for zinc and copper, and more efficient refining methods for these primary ores of tellurium and indium. Developments in supply technology, such as extracting tellurium from manganese nodules on the sea floor, could also ease the potential materials gap. But improvements in PV technology would likely be the main driver: (1) technologies could use thinner layers than those used today, by a factor of 10; (2) materials lost during layer fabrication could be reclaimed and used; and (3) elements such as gallium or aluminum could be substituted for indium. We can also expect additional technological improvements over the next five decades that we cannot

currently foresee and that would allow us to reach even 500 GW/yr of production from each of these technologies.

## References

- B. Andersson, "Materials Constraints on Technology Evolution." Thesis, Chalmers University of Technology and Goteborg University, Goteborg, Sweden, 2001.
- A. Belaidi, K. Ernst, M.C. Lux-Steiner, and R. Konenkamp, "Solar cell with extremely thin absorber on highly structured substrate." *Solar Energy Materials and Devices* 67,89, 2001.
- R. Dones and R. Frischknecht, from "Environmental Aspects of PV Systems."
- J. Guilinger, "Assessment of Critical Thin-Film Resources." Contract RAF-9-29609, World Industrial Minerals, Golden, CO (for Indium, Gallium, and Tellurium), 1999.
- R. von Guttenberg, Strathcona Mineral Services Ltd. Review of Indium Resources and Supply, for Davis, Joseph, and Negley, Austin, Texas, September 2001.
- T. Hansen, Chief Engineer, private communication. Springerville, Tucson Electric Power, 2003.
- International Copper Study Group, [http://mmsd1.mms.nrcan.gc.ca/icsg/focus/copper\\_world/production\\_consumption.htm](http://mmsd1.mms.nrcan.gc.ca/icsg/focus/copper_world/production_consumption.htm), 1998.
- R. Konenkamp, multiple publications, <http://web.pdx.edu/~rkoefetacell.html>, 2003.
- E. Nieuwlaar, E. Alsema (eds), IEA PVPS Task 1 Workshop. 25–27 June 1997, Utrecht, The Netherlands, Report no. 97072, Utrecht University, 1997.
- USGS, Historical Statistics for Mineral Commodities in the United States, <http://minerals.usgs.gov/minerals/pubs/of01-006/index.html>, 2003.

**Figure 1. Extractable versus Needed Indium (In) and Tellurium (Te) for Growth to 20 GW/yr**



Note: Assumes historical extraction growth rates for copper (Cu) and zinc (Zn) continue, and current PV designs remain in use.

For more information on PV, please read the other PV FAQs in this series. You can order hard copies of the FAQs from the National Center for Photovoltaics, or visit our Web site at [www.nrel.gov/ncpv](http://www.nrel.gov/ncpv).

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